Appendix N. Geoindicators Scoping Report for Arches National Park, Canyonlands National Park, Capitol Reef National Park, and Natural Bridges National Monument

This Appendix presents the body of the geoindicators scoping report. Of the several appendices that accompanied the original geoindicators report, only one is included here (Appendix I. Recommendations Table). Other appendices are available upon request from the NCPN.

Geoindicators Scoping Report for Arches National Park, Canyonlands National Park, Capitol Reef National Park, and Natural Bridges National Monument

Strategic Planning Goal Ib4

June 3-5, 2002
Moab, Utah

Compiled by Andy Pearce
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Contents

Scoping Summary

Introduction

From June 3-5, 2002, staff of the National Park Service, Utah Geological Survey, U.S. Geological Survey, Bureau of Land Management, Northern Arizona University, and Brigham Young University participated in a geoindicators scoping meeting in Moab, Utah for four National Park Service units in southeastern Utah. The four parks were Arches National Park (ARCH), Canyonlands National Park (CANY), Capitol Reef National Park (CARE), and Natural Bridges National Monument (NABR).

Purpose of meeting

The purpose of the meeting was to bring together park staff, geoscientists, and other resource specialists to address the issue of human influences on geologic processes in the four park areas. The group used collective knowledge of the four parks' geology and natural resources to identify the geologic processes active in the parks, to identify the human activities affecting those processes, and to develop recommendations for long-term monitoring of geoindicators in conjunction with park Vital Signs monitoring.

In addition, the Northern Colorado Vital Signs Network is coming on-line in fiscal year 2002 and will be receiving its first funding for Vital Signs monitoring. The scoping meeting was timed so the Network could use the information gained during the meeting in the Vital Signs selection process.

This report summarizes the group's discussions and provides recommendations for studies to support resource management decisions, inventory and monitoring projects, and research needed to fill data gaps.

Government Performance and Results Act (GPRA) Goal Ib4

This meeting satisfies the requirements of the GPRA Goal Ib4, which is a knowledge-based goal that states, "Geological processes in 53 parks [20% of 265 parks] are inventoried and human influences that affect those processes are identified." The goal was designed to improve park managers' capabilities to make informed, science-based decisions with regards to geologic resources. It is the intention of the goal to be the first step in a process that will eventually lead to the mitigation or elimination of human activities that severely impact geologic processes, harm geologic features, or cause critical imbalance in the ecosystem.

Because GPRA Goal Ib4 inventories only a sampling of parks, information gathered at the four parks may be used to represent other parks with similar resources or human influences on those resources, especially when findings are evaluated for Servicewide implications.

Geoindicator background information

An international Working Group of the International Union of Geological Sciences developed geoindicators as an approach for identifying rapid changes in the natural environment. The National Park Service uses geoindicators during scoping meetings as a tool to fulfill GPRA Goal Ib4. Geoindicators are measurable, quantifiable tools for assessing rapid changes in earth system processes. Geoindicators evaluate 27 earth system processes and phenomena (Appendix A) that may undergo significant change in magnitude, frequency, trend, or rates over periods of 100 years or less and may be affected by human actions (Appendix B). Geoindicators guide the discussion and field observations during scoping meetings (Appendix C). The geoindicators scoping process for the National Park Service was developed to help determine the studies necessary to answer management questions about what is happening to the environment, why it is happening, and whether it is significant.

Aspects of ecosystem health and stability are evaluated during the geoindicators scoping process. The geologic resources of a park—soils, caves, streams, springs, beaches, volcanoes, etc.—provide the physical foundation required to sustain the biological system. Geological processes create topographic highs and lows; affect water and soil chemistries; influence soil fertility and water-holding capacities, hillside stability, and the flow regimes of surface water and groundwater. These factors, in turn, determine where and when biological processes occur, such as the timing of species reproduction, the distribution and structure of ecosystems, and the resistance and resilience of ecosystems to human impacts (Appendix D).

Park Selection

These parks were selected to represent the Northern Colorado Plateau Network (NPCN) of parks. The parks will be the foci of research and development for protocols associated with vital-signs monitoring at NCPN parks and monuments. Geologic resources and processes found in these four parks are generally representative of those found throughout the rest of the NCPN, and considerable geologic research has been conducted in them previously.

Summary of Results and Recommendations

During the scoping meeting, geoindicators appropriate to Arches National Park, Canyonlands National Park, Capitol Reef National Park, and Natural Bridges National Monument were addressed. Of the 27 geoindicators (Appendix A), 21 were recognized as on-going processes to varying degrees in the four parks. An additional four geologic issues that are not part of the original geoindicators were also discussed (i.e., fire occurrence, atmospheric deposition, paleontological resources, and climate), as was an issue called “ecosystem response to geomorphic processes.” The issues surrounding each geoindicator were identified, and participants rated the geoindicator with respect to the importance to the ecosystem, human impacts, and significance for resource managers (Geoindicators table). A compilation of the notes taken during the scoping session (Appendix G) and field trip (Appendix H) are included in the appendices. These notes may highlight additional information regarding geoindicators that may be useful to resource managers.

During the geoindicators scoping meeting, participants identified studies to support resource management decisions, inventory and monitoring projects, and research to fill data gaps at all four parks. The recommendations that follow are not listed in any order of priority, but are intended to help guide park managers when making decisions regarding natural resource management needs. The recommendations that are listed are by no means inclusive of all possible geological research and monitoring. A table that lists all the recommendations made during the meeting can be found in Appendix I.

Table 1. Geoindicator table for Arches, Canyonlands, Capitol Reef national parks and Natural Bridges National Monument

Geoindicators	**Importance to park ecosystem**				***Human Impact**				****Significance to natural resource managers**			
	CANY	ARCH	NABR	CARE	CANY	ARCH	NABR	CARE	CANY	ARCH	NABR	CARE
ARID AND SEMIARID												
Soil crusts and pavements	5	5	5	5	5	5	5	5	5	5	5	5
Dune formation and reactivation	3	3	1	3	1	2	1	3	1	2	1	4
Dust storm magnitude, duration and frequency	1	1	1	1	5 1	5 2	5 1	5 3	3	3	3	3
Wind erosion (and deposition)	5	5	5	5	5 1	5 2	5 1	5 3				
SURFACE WATER												
Stream channel morphology	5	5	5	5	5	5	5	5	5	5	5	5
Stream sediment storage and load	5	5	5	5	5	5	5	5	5	5	5	5
Streamflow	5	5	5	5	5	5	5	5	5	5	5	5
Surface water quality	5	5	5	5	5	5	5	5	5	5	5	5
Wetlands extent, structure, hydrology	5	5	5	5	5	5	5	5	5	5	5	5
GROUNDWATER												
Groundwater quality	5	5	5	5	U	4	U	4	4	4	4	3
Groundwater level (and discharge)	5	5	5	5	5	5	5	5	5	5	5	5
SOILS												
Soil quality	5	5	5	5	1 5	1 5	1 5	1 5	5	5	5	5
Soil and sediment erosion (and deposition by water)	4	4	4	5	3 5	1 5	1 5	3 5	4	4	4	5
Sediment sequence and composition	1	1	1	1	4	4	4	5	3	3	3	3
HAZARDS												
Landslides, rockfalls, debris flows	3	2	2	3	1	1	1	1	1	1	1	2
Seismicity	2	1	1	1	3	3	0	0	1	1	1	1
Surface displacement (salt dissolution)	3	2	1	2	0	0	0	0	2	1	1	1
Fire occurrence	2	2	1	1	5	5	5	5	1	1	1	1
OTHER												
Atmospheric deposition (N, SO_4)	1	1	1	1	3	3	3	3	1	1	1	1
Paleontological resources	1	1	1	1	1	3	3	3	1	3	3	3
Climate	5	5	5	5	1	1	1	1	5	5	5	5

Table 1 cont.

Geoindicators	Importance to park ecosystem				*Human Impact				**Significance to natural resource managers			
	CANY	ARCH	NABR	CARE	CANY	ARCH	NABR	CARE	CANY	ARCH	NABR	CARE
OTHER												
Ecosystem structure and function characteristics as integrated indicators of geophysical (i) environments, (ii) processes, and (iii) changes/disturbances.	5	5	5	5	5#	5#	5#	5#	5	5	5	5
0 - Not Applicable (N/A) 1 - LOW or <u>no substantial</u> influence on, or utility for 3 - MODERATELY influenced by, or has some utility for 5 - HIGHLY influenced by, or with important utility for U - Unknown; may require study to determine applicability	*Includes current and potential impacts. If 2 rows, top = impacts of out-of-park activities on within-park condition; bottom = impacts of within-park activities. **Synthesis of first two columns and other miscellaneous factors #process specificity											

Significant geoindicators

The following is a summary of the results for the 11 geoindicators that rated the highest in all three categories, as well as the recommendations for these geoindicators that were proposed during the meeting. A summary of the scoping session discussion and the field trip are included in Appendix G and H, respectively. These notes highlight additional information regarding geoindicators that may be useful to resource managers.

<u>Desert surface crusts (biological and physiochemical) and pavements</u>

Biological soil crusts composed of varying proportions of cyanobacteria, lichens, and mosses are important and widespread components of terrestrial ecosystems in all four parks, and greatly benefit soil quality and ecosystem function. They increase water infiltration in some soil types, stabilize soils, fix atmospheric nitrogen for vascular plants, provide carbon to the interspaces between vegetation, secrete metals that stimulate plant growth, capture nutrient-carrying dust, and increase soil temperatures by decreasing surface albedo. They affect vegetation structure directly due to effects on soil stability, seedbed characteristics, and safe-site availability, and indirectly through effects on soil temperature and on water and nutrient availability. Decreases in the abundance of biological soil crusts relative to physicochemical crusts (which can protect soils from wind erosion but not water erosion, and do not perform other ecological functions of biological crusts) can indicate increased susceptibility of soils to erosion and decreased functioning of other ecosystem processes associated with biological crusts.

Human impacts

Off-trail use by visitors, past trampling by cattle in Arches and Canyonlands national parks, and present trampling by cattle in Capitol Reef National Park have damaged soil crusts significantly in some areas. Soil nutrient cycles, as well as most other benefits of biological soil crusts, have been compromised in these areas.

Recommendations

Inventory condition and distribution of biological soil crusts.
Investigate connection between ecosystem function and biological crusts.
Map crust communities in relation to environmental factors.
Study crust recovery rates and susceptibility to change.
Study crust population dynamics and conditions.

<u>Wind erosion and deposition</u>

In addition to water, wind is a major force that can redistribute soil and soil resources (e.g., litter, organic matter, and nutrients) within and among ecosystems. Erosion and deposition by wind is important in all four parks and can be accelerated by human activities. Accelerated losses of soil and soil resources by erosion can indicate degradation of arid-land ecosystems because ecosystem health is dependent on the retention of these resources.

Human impacts

Trampling and vegetation alteration by livestock as well as human recreational activities such as hiking, biking, and driving off of established trails and roads can destabilize soils and increase soil susceptibility to wind erosion. Some localized heavy visitation areas within parks have seen crust death by burial from windblown sands when nearby crusts have been trampled, such as in the Windows area of Arches National Park.

In addition, wind erosion and sediment transport may be strongly impacted by land-use practices outside the parks. Eolian sand from disturbed surfaces may saltate onto undisturbed ground, burying and killing vegetation and/or biological soil crusts, or breaking biological soil crusts to expose more soil to erosion. Because park management practices limit or prohibit off-road travel, human impacts within the parks primarily are associated with off-trail hiking in high-use areas. Where livestock grazing or trailing is still permitted (e.g., CARE), accelerated soil erosion can be more extensive.

Recommendations

Monitor movement of soil materials (see Recommendations table).
Investigate ecosystem consequences of movement (**Contact:** Jason Neff, 303-236-1306, jneff@usgs.gov**)**
Investigate natural range of variability of soil movement in relation to landscape configuration and characteristics. (**Contact:** Jason Neff, 303-236-1306, jneff@usgs.gov)

<u>Stream channel morphology</u>

The morphology of stream channels impacts the vegetative structure of the riparian corridor, affects the height of the water table, and affects the energy of water flow downstream (which affects erosion rate and water quality). Stream channels are vital components of aquatic and riparian ecosystems in these arid-land parks.

Human Impacts
Potential for human impact on stream channel morphology is great. These impacts include building parking lots and structures in or near channels, building structures in floodplains (e.g., culverts and bridges), livestock grazing in uplands and stream channels, roads and trails up streambeds, introduction of exotic species, and impacts from flow regulation and diversion.

Recommendations
Conduct hydrologic condition assessment to identify actual and potential “problem reaches” for prioritized monitoring.
Once “problem reaches” are identified, monitor with repeat aerial photographs.
Once “problem reaches” are identified, monitor with repeated cross-sections. Some data are available for Capitol Reef, Canyonlands, and Arches national parks. (See Recommendations table).

Stream sediment erosion, storage and load
Participants added “erosion” in order to clarify and encompass the total geomorphic picture regarding stream function. The original title is “stream sediment storage and load.” This geoindicator is important to the ecosystem because sediment loads and distribution affect aquatic and riparian ecosystems, and because sediment loading can result in changes to channel morphology and overbank flooding frequency.

Human impacts
The potential for human impact to stream sediment erosion, storage, and load is great. These impacts include building parking lots and structures in or near channels, building structures (e.g., culverts and bridges) in floodplains, grazing in uplands and stream channels, roads and trails up streambeds, introduction of exotic species, and impacts from flow regulation and diversion.

Recommendations
Conduct research concerning ungaged stream sediment storage and load. There are no data available except on the main stem of the Colorado River at Cisco, Utah, and the Green River at Green River, Utah.
Measure sediment load on streams of high interest for comparative assessment. Data will provide information for making management decision.

Streamflow
Streamflow is critical to the maintenance of aquatic and riparian ecosystems. Streamflow impacts the structure of the riparian corridor, affects the height of the water table, and affects water quality and erosion rates.

Human impacts
The potential for human impact on streamflow is great. These impacts include building parking lots and structures in or near channels, building structures (e.g., culverts and bridges) in floodplains, grazing in uplands and stream channels, roads and trails up streambeds, introduction of exotic species, and impacts from flow regulation and diversion.

Recommendations
Identify important hydrologic systems that would benefit from knowledge of streamflow. Existing gauging stations are located on the Green River (Green River, Utah), San Rafael River (near Green River, Utah.), Fremont River (at Cainville, Utah, and above Park at Pine Creek.), and on the Muddy River. Many other gauging stations exist (see USGS Web site). Additional data exists for streams in Capitol Reef National Park and for Courthouse Wash in Arches National Park. Other relevant data exists with the local U.S. Geological Survey, Water Resources Division.
Research effects of land use and climatic variation on streamflow.
Investigate paleoflood hydrology.

<u>Surface water quality</u>
For detailed understanding of the issues and what has been done with regards to water quality data for the four NPS units, see the June, 2002, trip report prepared by Don Weeks in Appendix J. There are a number of park-specific water resource reports cited in the report that are particularly pertinent.

Human impacts
The potential for negative affects on groundwater quality by human activity is significant. The following are specific issues that could impact groundwater quality:
Herbicide use to decrease tamarisk populations.
Trespass cattle at springs.
Abandoned oil and gas wells within and close to NPS boundaries may result in saline waters infiltrating into groundwater supplies.
Abandoned uranium mines and mills.
Impacts from recreational uses (these have not been quantified).

Human impacts in Canyonlands National Park
Old landfill in Needles District (approx. 1 mile from Visitor Center, and 3,000 ft from a domestic well) had unregulated dumping from 1966-1987.
Texas Gulf Potash Mine located downriver from Moab on the Colorado River.

Human impacts in Arches National Park
Contamination from the Atlas tailings pile.
Water rights associated with springs and wells near the park boundary, particularly those associated with Courthouse Wash, Lost Spring Canyon, and Sevenmile Canyon.

Human impacts in Natural Bridges National Park
Abandoned copper and uranium mines.

Human impacts in Capitol Reef National Park
Natural radioactivity may occur in portions of the Fremont River where it flows through uranium-ore bearing strata of the Chinle Formation.
Pesticide use by park managers to maintain the historic orchards.

Recommendation
Obtain information about existing baseline water quality data for all four parks (**Contact**: Don Weeks, 303-987-6640, don_weeks@nps.gov). Also see Don Weeks June, 2002, trip report in Appendix J.

Wetlands extent, structure, and hydrology
Wetlands are important ecosystems because they stabilize streambanks, act as filters to improve water quality, attenuate floodwaters, enhance biodiversity (important habitat for amphibians, reptiles, birds, and Threatened and Endangered Species), are highly productive in terms of biomass and nutrient productivity, and are valuable water sources for wildlife and recreationists.

Human impacts
The potential for human impacts on wetlands is great. These impacts include building parking lots and structures in or near channels, building structures (e.g., culverts and bridges) in floodplains, grazing in uplands and stream channels, roads and trails up streambeds, introduction of exotic species, and impacts from flow regulation and diversion. In addition, agricultural activities and past extirpation of beaver have affected wetlands.

Recommendations
Inventory location, character, and conditions of wetlands in all four parks.
Inventory distribution of exotic species in wetlands.
Monitor groundwater levels and surface elevations.
Investigate age-structure and populations of woody riparian plants in relation to land use history.
Investigate links between amphibian health attributes and wetland health.

Groundwater quality
The quality of groundwater in the parks has a high impact on hanging gardens, which are located in all four parks. Hanging gardens are unique features that contain rare plant species, and provide important wildlife habitat. Groundwater quality is also an issue for safety and health regarding water quality for human use. To further understand what the issues are and what has been done with regards to water quality data for the four NPS units, see Appendix J.

Human impacts
The potential for negative affects on groundwater by human activity is significant. All four parks identified specific issues that could impact groundwater quality.

Human impacts in Arches National Park
Grazing near Courthouse Wash and Sevenmile Canyon springs may have affected groundwater quality.
The effects of mining and oil and gas drilling are unknown.
Human impacts in Canyonlands National Park
Old landfill in the Needles District had unregulated dumping from 1966-1987.
Oil well sites had improper dewatering.

The effects of mining and oil and gas drilling are unknown.

Human impacts in Capitol Reef National Park
The effects of mining and oil and gas drilling are unknown.
There is standing water in mines within the park.
There is a National Park Service septic field near the Fremont River.

Human impacts in Natural Bridges National Monument
The impacts of copper and uranium mining and oil and gas drilling are unknown.

Recommendations
Locate and inventory all seeps, springs, and hanging gardens.
Prioritize seeps, springs, and hanging gardens for assessment of water quality.
Acquire plugging records of oil and gas wells potentially connected to park groundwater systems (**Contact:** Bob Higgins, 303-969-2018, bob_higgins@nps.gov).
Use geochemical indicators to investigate groundwater flow areas, flow directions and recharge area, and groundwater age.
Identify and study potential sources for groundwater quality impacts at all four parks, including those listed above (**Contact**: Don Weeks, 303-987-6640, don_weeks@nps.gov). See Appendix J.

<u>Groundwater level and discharge</u>
Outside the river corridors in Canyonlands and Capitol Reef national parks, groundwater supplies much of the water available for wildlife, and supplies 100% of the park's water supply for human use.

Human impacts
Groundwater is a limited resource, and the potential for human impact is great. Current human impacts are poorly understood.

Recommendations
Inventory and research are needed concerning groundwater quality, level, and discharge.
Install transducers and dataloggers in wells.
Develop methods for measuring water discharge from seeps and hanging gardens (**Contact:** Bob Webb, 520-670-6671, rhwebb@usgs.gov).
Investigate additional methods to characterize groundwater recharge areas and flow directions (**Contacts:** Charlie Schelz, 435-719-2135, charlie_schelz@nps.gov and Rod Parnell, 928-523-3329, roderic.parnell@nau.edu).

<u>Soil quality</u>
Soil quality affects moisture retention, nutrient cycling, soil-food webs, and aggregate structure. Soil also provides biogeochemical and hydrologic support for terrestrial productivity, especially vegetation growth. Soil quality degradation results in loss of certain ecosystem functions, such as nutrient cycling.
Human impacts
Due to past and present grazing in the parks, nutrient cycles have not recovered.

Recommendations
Assess existing soil-crust conditions in relation to potential (as an indicator of soil quality) and in relation to soil maps.
Repeatedly measure soil quality in disturbed sites to gain understanding of recovery rates in relation to environmental factors, such as soil texture, topographic position, and climate.
Quantify natural range of variability in quality in relation to environmental factors.
Develop predictive model for potential biological soil crust distribution/structure/function in relation to environmental factors, such as soil texture, soil chemistry, topographic position, and climate.
Investigate susceptibility to change (e.g., climate and UV).
Study resistance and resilience of soil to human disturbances.

<u>Soil and sediment erosion and deposition by water</u>
During the discussion of this geoindicator, participants chose to focus on water transport and deposition, therefore the words, “and deposition by water” were added to this geoindicator. Transport and/or loss of soil may result in degradation of soil quality (see Soil quality geoindicator).

Human impacts
In general, past grazing practices has caused soil erosion in all four parks. There is still occasional trespass of cattle in Arches and Canyonlands national parks and Natural Brides National Monument.

Human impacts in Capitol Reef National Park
Grazing is still permitted.
Topographic gradients are high; therefore, erosion along roads (both currently-used roads and those used for past practices, such as mining) and cow trails is potentially great.

Recommendations
Investigate/develop methods for monitoring erosion and deposition quantitatively and affordably, and determine the best locations to monitor (**Contact:** Bob Webb, 520-670-6671, rhwebb@usgs.gov).
Assess conditions of soil erosion (e.g., qualitative hydrologic function).

Ecosystem response to geomorphic processes

Because many types of ecosystems are highly dependent on the geomorphic process and substrate, ecosystem response to geomorphic processes is highly important to park ecosystems. Disturbance to ecosystems is inevitable, whether the disturbance is human or natural caused. Management actions that attempt to mitigate disturbances, and particularly restoration of disturbed areas, may be influenced by the types of geomorphic processes involved and/or the nature of geomorphic substrates. Knowledge of predicted ecosystem responses to disturbances may affect the decision of whether to actively rehabilitate a disturbed site or whether to allow it to recover naturally. If active rehabilitation or restoration is chosen, this knowledge should determine what types of species are suitable for the underlying geomorphic conditions. Land-use practices, as well as climatic fluctuations may have an impact on ecosystem response. The perceived significance by managers depends upon need in the wake of an important disturbance that may instigate a management response.
(**Contacts**: Bob Webb, 520-670-6671, rhwebb@usgs.gov; and Rod Parnell, 928-523-3329, roderic.parnell@nau.edu).

Recommendations

Acquire high quality surficial geology, soil, and vegetation maps for all four parks. Current availability of soil and geologic mapping varies among the parks.
Determine what to monitor, where, and with what attributes/indicators.
Research spatial and temporal relations among ecosystem structure and function, geologic substrates, and geomorphic processes.
Assess change-detection methods.

List of Participants

National Park Service
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Table 2. Recommendations

Geoindicators	**Baseline Data (existence and adequacy)**	**I & M (I&M needs)**	**Research**
Ecosystem structure-and-function characteristics as integrated indicators of geophysical (i) environments, (ii) processes, and (iii) changes/disturbances.	- process-level data are almost non-existent - of available, most information is for NEED-CANY - current availability and adequacy of soil and geologic mapping varies among parks - 10-m DEMs are available for all four parks - 1:12K aerial photos & DOQQs to be acquired within next year - veg maps scheduled to be completed within 4 years	- surficial geology maps - soil maps - vegetation maps - research will determine what to monitor, where, and with what attributes / indicators	- spatial and temporal relations among ecosystem structure / function, geologic substrates (e.g., chemistry, texture, landform attributes), and geomorphic processes - assess change-detection methods - determine which attributes are best suited as indicators
ARID AND SEMIARID			
1. Desert surface crusts (bio & physicochem) and pavements (same for all 4 parks)	- ARCH has best existing data; needs at CANY, NABR and CARE are greater	- inventory current distribution, composition and condition relative to potential	- investigate connection between ecosystem function and biocrusts - develop predictive map of potential composition / structure of crust communities in relation to environmental factors - investigate recovery rates in relation to disturbance and environmental factors - determine susceptibility to change, e.g. changing climate, UV - study population dynamics and condition in disturbed vs. undisturbed

Table 2 cont.

Geoindicators	Baseline Data (existence and adequacy)	I & M (I&M needs)	Research
ARID AND SEMIARID			
2. Dune formation and reactivation	- existing data almost nonexistent - surficial geology map for small portion of NEED-CANY	- inventory required (geologic maps omit sand sheets) – i.e., map spatial distribution of sand sheets and dune features - following inventory, assess and categorize dunes / sand sheets with respect to (re)activation susceptibility - potentially monitor by repeated aerial photography (possibly with 5-year repeat interval)	- P/PE mapping to support susceptibility assessment (which will require automated climate stations) - research concerning potential (re)activation thresholds - investigate ecosystem consequences of dune reactivation
3. Dust storm magnitude, duration and frequency (bad-visibility days)	- currently being monitored at ISKY-CANY, ARCH, CARE - regional data are adequate, but local are not	- if there is a local issue....then local I&M data are required -otherwise, nothing additional is needed	- nothing locally
4. Wind erosion (ecosystem inputs / outputs of soil resources excluding water)	-some data are available from NEED-CANY for erosion & deposition - new dust traps recently installed at ARCH & ISKY-CANY (new inputs) - nothing elsewhere	- monitor movement of soil materials	- investigate better measurement / monitoring methods - investigate ecosystem consequences of movement - investigate natural range of variability in relation to landscape configuration and characteristics (Neff)

Table 2 cont.

SURFACE WATER			
5. Stream channel morphology	- some cross-section data are available for Salt Creek (NEED-CANY), Courthouse Wash (ARCH), and Lost Spring (ARCH) - gauging stations in Courthouse Wash - miscellaneous cross-section data from Fremont R. & some other CARE systems - 1:12K aerial photos & DOQQs to be acquired within next year	- conduct hydrologic condition assessments to identify actual / potential "problem reaches" for prioritizing monitoring (e.g., PFC) - monitor with repeat aerial photographs - monitor with repeated cross sections	
Geoindicators	**Baseline Data (existence and adequacy)**	**I & M (I&M needs)**	**Research**
SURFACE WATER			
6. Stream sediment erosion, storage and load	- no data available except for main stem of Colorado River (at Cisco) and Green River (at Green River, UT)		- conduct research concerning ungaged stream sediment storage and load - potential gaging of high-interest streams for comparative assessment of sediment measures in relation to management
7. Streamflow	- existing gages on Green R. (Green R. UT) San Rafael R. (near Green R.) Fremont R. (Cainville & above Park at Pine Crk.), Muddy River (uncertain location)...... –many other existing gages....see USGS website; - some additional flow data for CARE streams, Courthouse Wash ARCH - miscellaneous relevant data –see local USGS WRD -regionalized flood-frequency studies for UT and arid western-region states	- identify important hydrologic systems that would benefit from knowledge of streamflow - criteria: critical riparian systems, TES taxa, potential up-stream land-use effects, water-right issues, recreational use, management interest / controversy	- effects of land-use and climatic variation on stream flow - investigate paleoflood hydrology
8. Surface water quality	- see information compiled by CSU for NCPN		- investigate effects of sunscreen on water quality in springs

Table 2 cont.

9. Extent, structure, and hydrology of riparian / wetland systems	- see 5,6,7,8 above - current macroinvertebrate monitoring in SEUG - current riparian bird and vegetation monitoring in SEUG - limited amphibian inventory at CANY - see veg mapping comments elsewhere	- inventory location and character of wetlands (first step is to look at existing NWI maps—but these would only capture larger systems) - potentially conduct inventory of riparian & wetland condition (e.g., PFC) - inventory spatial distribution of exotics - monitor groundwater levels and surface elevations	- investigate age-structure of woody riparian plants in relation to land-use - investigate potential linkages between amphibian parameters and wetland health
Geoindicators	**Baseline Data (existence and adequacy)**	**I & M (I&M needs)**	**Research**
SURFACE WATER			
10. Lake levels and salinity			
GROUNDWATER			
11. Groundwater quality	-uncertainty exists concerning groundwater effects of old mines (all parks) and the buried landfill at NEED-CANY - baseline water quality data are available for some springs in SEUG, but not for seeps/hanging gardens	- conduct inventory (determine location) of all springs / seeps / hanging gardens (need in GIS) - assess current water quality in a prioritized subset of these, accounting for seasonal variability - (prioritized on basis of potential human use, potential human impact, ecological parameters) - inventory location and plugging record of oil/gas wells potentially connected to park groundwater systems	- use geochemical indicators to investigate groundwater flow areas, flow directions and recharge area, and groundwater age
12. Groundwater chemistry in the unsaturated zone			

Table 2 cont.

13. Groundwater level and discharge		- install transducers and dataloggers in wells (transducers measure pressure of the water in the well) -inventory and research (concerning groundwater quality and level/discharge) must be completed prior to monitoring	- investigate / develop methods for measuring water discharge from seeps and hanging gardens (Webb) - investigate additional methods to characterize groundwater recharge area and flow directions
14. Subsurface temperature regime			
15. Karst activity (salt)			
Geoindicators	**Baseline Data (existence and adequacy)**	**I & M (I&M needs)**	**Research**
SOILS			
16. Soil quality	- some data available for NEED, ARCH; very limited elsewhere	- assess existing bio crust condition in relation to potential (as indicator of soil quality) and in relation to soil map units - repeatedly measure soil quality in previously disturbed sites to gage recovery rates in relation to environmental factors	- quantify natural range of variability in relation to environmental factors - develop predictive model for potential biological soil crust distribution/structure/function in relation to environmental factors (bio crust as indicator of soil quality) - investigate susceptibility to change, e.g. changing climate, UV - resistance and resilience to disturbance factors

Table 2 cont.

17. Soil and sediment erosion & deposition by water (upland environments)	- current availability and adequacy of soil and geologic mapping varies among parks - 10-m DEMs are available for all four parks - 1:12K aerial photos & DOQQs to be acquired within next year - veg maps scheduled to be completed within 4 years - some data are available for fluvial erosion of sandy soils at NEED	- conduct condition assessments (e.g., qualitative hydrologic function—rangeland health) - stratify assessments in relation to landscape units and potential impacts - stratify monitoring in relation to landscape units and results of condition assessments	- investigate / develop methods for monitoring this quantitatively and affordably .... and determine where best to monitor (Webb)
18. Sediment sequence and composition	- some data are available from auger holes, soil pits, & micro sediment sequences from soil crusts at NEED & ARCH		- identify sites, acquire cores, analyze in relation to local and regional land-use histories (potential link with Colorado Plateau CESU); objectives are to quantify natural range of variability in sediment quantity and composition and effects of land use
Geoindicators	**Baseline Data (existence and adequacy)**	**I & M (I&M needs)**	**Research**
HAZARDS			
19. Slope failure (landslides)	- no data exist for rockfalls - data exist for debris flows in CANY along river	- use repeat ground and aerial photography to monitor debris flows in Cataract Canyon (for assessment of effects on navigation) - land slides should be reported if regularly occurring (e.g., to assess potential for damming creeks/canyons)	- continue studying spatiotemporal distribution of slope failures in relation to bedrock structure & lithology

Table 2 cont.

20. Seismicity	- the data exist and are quite adequate	- consider asking USGS to install seismic monitoring devices in parks (not necessary, but possibly interesting)	
21. Surface displacement (including salt dissolution features)	- graben offsets have been monitored at CANY - previous seismic data have been collected for CANY, ARCH	- continue to monitor graben offsets	
OTHER			
23. Atmospheric deposition (N, SO4)	- defer to air-quality monitoring		
24. Paleontological resources	- paleo survey has been conducted at ARCH; very limited info avail for other parks - limited surveys for potential Quaternary resources at all parks - geologic maps exist for all parks - preliminary literature searches for all parks have been conducted	- conduct comprehensive inventories - monitoring will be required, but needs will be contingent on inventory results	- research needs will follow from inventory results
Geoindicators	**Baseline Data (existence and adequacy)**	**I & M (I&M needs)**	**Research**
OTHER			
25. Climate	- CANY has 5 automated stations and 30-yr daily record - WRCC website provides long-term data for parks and surrounding stations - ARCH (~50 yr) & NABR have daily data - CARE has ~35 years of daily data - CARE has 3 years of data from automated station in the parking lot	- more automated stations needed - canvas for locations of additional / unofficial recording stations	- develop spatial model of rainfall to determine what locations would benefit from a station (to support monitoring) - develop spatial distribution of PET and climatic water balance as a function of landscape / substrate features (to support monitoring)